

Presented at Coastal Zone '93. Reprint from *Beach Nourishment Engineering and Management Considerations*. Volume in a series of volumes on Coastlines of the World. D.K. Stauble and N.C. Kraus (volume editors), O.T. Magoon (series editor), ASCE, New York, N.Y., pp. 176-190.

THE PROFILE VOLUME APPROACH TO BEACH NOURISHMENT

Timothy W. Kana, Ph.D.¹

ABSTRACT

The purpose of this paper is to outline a design approach to beach nourishment that emphasizes profile volumes and has been favored by our firm in about ten projects since 1985. Its advantages and disadvantages are outlined and related to other analytical techniques for predicting beach fill needs.

The South Carolina coast, where CSE projects totaling about 5 million cubic meters (6,500,000 cubic yards) have been constructed, is mesotidal with broad, wet-sand beaches and narrow, dry-sand areas. As a result, a large portion of the profile is intertidal and exposed to breaking waves. Unit profile volumes (the sand quantity between reference contours) are a primary basis for defining the condition of the beach, comparing one reach with another and computing surplus or deficit quantities. By selecting contours that encompass the entire surf zone from the base of foredunes to low-tide wading depth, daily and small-scale perturbations of beachface slope and beach morphology are ignored. An ideal present profile (IPP) is developed for the reach in question and used as a basis for comparison of profiles, for delineation of the natural "shoreline" in the absence of structures, and for estimate of sand deficits. Nourishment quantities are predicated on several factors, none of which relate directly to an equilibrium beach slope for the area, but in effect, account for the normal range of profile variations:

- 1) Comparison of unit-width volumes in scheduled nourishment areas with comparable "healthy" profiles having desirable beach dimensions.
- 2) Comparison of unit-width volumes alongshore to account for systematic variations between straight beaches and inlet-influenced beaches.
- 3) Comparison with historical volumetric losses to provide advance nourishment, as well as a quantity to make up a deficit.

- 4) Comparison with regional sand budgets and geomorphic models of sediment dispersal.
- 5) Consideration of unit costs and budgets available.

The last factor, in many cases, overrides all others. However, the four technical procedures provide a means of checking quantity estimates and tracking performance easily and realistically. While our final designs generally incorporate traditional analyses of waves, longshore transport, and depth of closure, the ideal profile and unit volume analyses are most important. Regardless of how a project is constructed, incident waves will soon modify the slope of the fill and redistribute it into an equilibrium profile and planform for that section of coast.

INTRODUCTION

The purpose of this paper is to outline a design approach to beach nourishment that emphasizes profile volumes and has been favored by our firm in about ten projects since 1985. Its advantages and disadvantages are outlined and related to other analytical techniques for predicting beach fill needs.

A fundamental requirement of beach nourishment design is information on profile geometry for the site in question. Numerous studies have documented statistical relationships between beach/foreshore slopes and sediment grain size (Bascom, 1951; Shepard, 1963) or slopes and wave energy (Wiegel, 1964; Komar, 1976). Work by Bruun (1954) and Dean (1977) has emphasized the applicability of the function, $h(y) = Ay^{2/3}$, to describe equilibrium foreshore slopes as a function of distance offshore, where h is the water depth some distance (y) offshore and A is an empirical coefficient related to sediment characteristics (i.e., grain size, fall velocity, etc.)

Dean's approach can be used to predict the expected adjusted width of the dry-sand berm after nourishment as a function of sediment grain size (Dean, 1991). This approach has been used in a number of nourishment designs including the 1986/1987 Myrtle Beach, South Carolina, project (Siah et al., 1985). Because the approach is basically two-dimensional, it appears to work best along straight, uninterrupted shorelines with shore-parallel contours. Such conditions occur along many microtidal, barrier island or mainland coasts. However, where inlets and associated ebb-tidal deltas occur, nearshore bathymetry becomes much more complex.

The 2-D equilibrium profile may not apply in areas of variable backshore conditions or complex bathymetry because of the occurrence and variability of nearshore bars or the interaction of wave- and tidal-generated currents. Antecedent topography, including submerged wave-cut planforms, may control the local profile closure depth in some areas. For example, some beach profiles are perched on a hard-bottom platform (e.g., Myrtle Beach, S.C., Gundlach et al., 1985). Application of the equilibrium profile relationship in these cases may miss primary inflection points at the toe

¹CSE Coastal Science & Engineering, Inc., PO Box 8056 Columbia SC 29202 [803-799-8949; FAX 803-799-9481]

of the foreshore and overestimate the profile closure depth. In the context of beach nourishment, this may result in an overestimate of fill requirements.

Tests of Dean's equilibrium profile relationship show statistical deviations occur (e.g., Work and Dean, 1991). For nourishment projects, even a 5 percent deviation from the predicted equilibrium slopes can be important over a typical 150-m (500-ft) foreshore width. Such minor variations in slope will translate into major differences between the predicted and resulting berm width after nourishment.

TRADITIONAL NOURISHMENT DESIGN APPROACH

The traditional approach to nourishment design in the United States (CERC, 1984) involves use of design beach slopes to compute fill requirements. The foreshore slope is generally designed to parallel the natural beach slope above low water. Site-specific profile surveys are used to develop statistically representative slopes above and below water. Most designs appear to be based on a simple profile geometry, beginning with a flat berm (zero slope) of the desired width at the natural berm elevation for the site and an average foreshore slope from the berm crest to estimated closure depth [e.g., CSE (1991), Hunting Island (S.C.) project plans (1:35 foreshore slope)]. Some designs have applied a composite slope above and below low water [e.g., CSE (1990a), Seabrook Island plan along an inlet margin], or above and below mean high water [USACE (1992), Folly Beach, S.C.]. A number of projects have used an arbitrary slope [i.e., one not related to the natural slope of the area [e.g., Olsen Associates (1989) for Hilton Head Island, S.C.; 1:20 foreshore slope versus 1:40 typical natural slope]].

Construction of the beach may or may not attempt to produce the design slopes depending on the method and logistical constraints. However, the unit-fill quantities will generally be predicated on the design volumes derived from the assumed slopes (CERC, 1984). It is apparent waves and currents will eventually produce an equilibrated profile, whatever that may be for a site, regardless of the method of construction. If most of the fill is placed above low water (as is the case for most trucking operations), material will slough into deeper water. If the lower foreshore alone is nourished, onshore transport will redistribute some material to the berm and restore a natural profile.

Nourishment success under the traditional design approach depends to a large extent on the ability to predict the resulting foreshore slopes. Construction efficiencies for hydraulic projects are also highly dependent on this because, in general, it is difficult to control the underwater slope as the fill is placed. Getting the design quantity of fill in a section depends on selecting the correct berm width which yields the desired unit volume for the constructed foreshore slope. This is easier in microtidal settings with constant wave energy. In mesotidal settings with large fortnightly variations in tide range, the constructed slopes will vary as a function of tide range and wave energy (CSE, 1991). During spring tides, the slurry head from the berm to low water is

higher, producing a greater drawdown of material on the foreshore, in effect producing a gentler slope. Neap tides produce less of a slurry head and yield higher foreshore slopes. Differences in drawdown are also produced by variations in wave energy with higher waves tending to flatten the foreshore of a fill just as a natural beach is flattened.

Given the variability in profiles for certain shorelines, particularly along South Carolina's mesotidal coast (Brown, 1977), we have found it useful to emphasize a different approach for nourishment design, one that favors profile volumes for establishing quantity estimates and evaluating performance.

ELEMENTS OF THE PROFILE VOLUME APPROACH

Several elements distinguish CSE's profile volume approach from the traditional CERC (1984) approach to nourishment:

- 1) Use of conceptual geomorphic models of net sand transport patterns around tidal inlets.
- 2) Designing for littoral cells that exist for the reference time period.
- 3) Application of a site-specific ideal present profile (IPP) (Kana et al., 1984).
- 4) Emphasis on volumetric rather than linear erosion rates (CSE, 1990a).

While these elements are emphasized in our approach, traditional CERC (1984) methods, application of shoreline simulation models, equilibrium profile models, and computations of longshore transport rates by compartment are incorporated at the design stage as appropriate for each project.

The first element involves development of a conceptual geomorphic model for the site (Kana and Stevens, 1992). Such models draw on the extensive descriptive literature of coastal processes and geomorphology and consider the tectonic framework (Inman and Nordstrom, 1971), regional geology, barrier island morphology (Hayes, 1979), tidal inlet sediment dynamics (e.g., Hayes, 1980), hydrographic regime (Nummedal and Fischer, 1979), recent (< 100 years) erosion history, nearshore bathymetry, and beach/dune morphology and vegetation patterns. Such qualitative models are a starting point for quantitative studies and for detecting systematic longshore variations in profile geometry or shoreline planform. An example used in the 1991 Hunting Island nourishment project is given in Figure 1. Preparing such models forces the design team to think about the basic controls on sand transport for a site. The model provides an overview of erosion factors which can be tested with quantitative studies and used to describe the rationale for a project. Such models have been incorporated in promotional material to help generate community support for nourishment projects [e.g., Hilton Head Island, S.C. (1990); Seabrook Island, S.C. (1990)]. For the

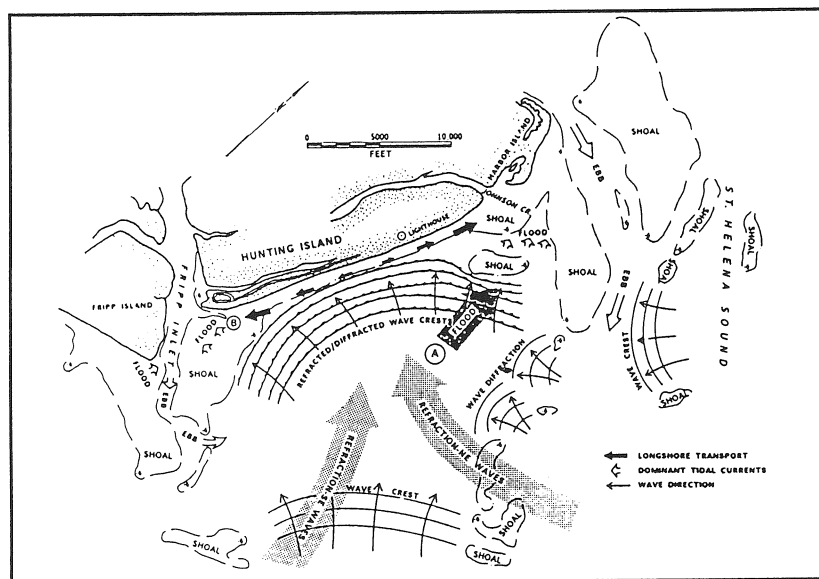


FIGURE 1. Geomorphic model of coastal processes producing refraction and diffraction around shoals and sand transport away from the center of Hunting Island [from CSE, 1990b].

layman, geomorphic models cut through the technical details that are often lost in public forums. For technical experts, geomorphic models provide a guidepost for critically evaluating a project and focussing on uncertain design parameters.

The second element involves delineation of compartments or littoral cells. Inlets and headlands are common boundaries for shoreline compartments. In general, boundaries reflect littoral barriers, or distinct transition zones from erosion to accretion, or a major change alongshore in the erosion rate. A common delineation subdivides compartments between (directly) inlet-influenced shorelines and open-coast shorelines (e.g., see Kana and Stevens, 1992, p. 41). A reference time frame is considered whereby the compartment boundaries reflect the local cycles and aerial extent of erosion- and accretion-associated changes at tidal inlets (e.g., inlet migration or shoal bypassing) (Sexton and Hayes, 1983; Kana et al., 1985). The time frame may reflect the period over which existing shore-protection structures, such as groins, have been in place. Littoral cells and compartment boundaries should reflect expected conditions over a specified time period appropriate to the site rather than some uniform time period such as that prescribed by certain federal projects.

The third element involves selection of a site-specific ideal profile (Kana et al., 1984) which is described in detail the next section.

The fourth element is determination of volumetric erosion rates for the littoral cell and subcompartments in question. Sequential, controlled profile surveys from the dunes to closure depth are critical for this analysis. Linear erosion rates for particular contours can be derived easily from profiles, but volumetric estimates are not reliably extrapolated from single-contour, shoreline movement studies. In South Carolina, private and public beach profile surveys spanning 5-30 years are available for virtually every developed beach at spacings ranging from 100 m (330 ft) to 600 m (2,000 ft).

Two rates are typically developed in CSE designs (Siah et al., 1985): (1) long-term (>10-year) annual averages by reach, and (2) short-term (<10-year) annual averages. The adopted rate for estimating advance nourishment quantities is generally weighted to the higher value which most often is derived from the short-term data. At Myrtle Beach, the short-term erosion rate for a three-year period before nourishment was on the order 6.25 cubic meters per meter per year ($m^3/m/yr$) [2.5 cubic yards per foot per year (cy/ft/yr)] to low-tide wading depth (estimated 4.0 cy/ft/yr to profile closure). In contrast, the 28-year erosion rate was almost one order of magnitude lower at 1.0 m^3/m (0.4 cy/ft/yr) (Kana et al., 1984).

If performance of a fill is to be measured against the background erosion rate, the design should clearly document which rate was assumed for planning and why. Given the common variability in erosion rates alongshore, CSE establishes an average rate for each subcompartment in a littoral cell and uses that rate as a benchmark for future comparisons. Where the shoreline is relatively straight with parallel contours, profile spacing up to 600 m (2,000 ft) may be acceptable. However, the majority of candidate sites for CSE projects involves profile spacing at less than 300 m (1,000 ft). Around tidal inlets, spacing of regularly surveyed profiles can be as low as 50 m (160 ft). Such spacing is needed to account for longshore variations produced by rhythmic beach forms.

The Ideal Present Profile (IPP)

The third element of CSE's profile volume approach to nourishment involves application of an *ideal present profile* (IPP). The IPP is a characteristic profile for the project shoreline that represents an ideal cross-section. Much of the variation in beach volume or beach width along developed shorelines (e.g., Myrtle Beach) is more a function of variation in the backshore (dunes, landscaping, and shore-protection structures) rather than a variation caused by coastal processes, sediment type, or other nondevelopment factors. An *ideal profile* is considered to be one in which a foredune exists and the beach profile is typical of most sections in terms of beach width, slopes, and unit volumes.

One purpose of determining the IPP is to establish where the shoreline would be in the absence of shore-protection structures or varying dune widths and volumes. It is based on an "average" profile from the shoreline in question, therefore reflecting conditions at the time of the analysis.

The procedure for developing an ideal profile (Kana et al., 1984) is as follows:

- 1) Select profiles from the site in question or a comparable site that are considered to be representative of acceptable conditions (i.e., ones featuring a healthy foredune, existing dry beach, and foreshore features common in the area).
- 2) Match the profiles at a common backshore contour which provides the closest statistical match. Figure 2 shows an example for ten ranges at Myrtle Beach, South Carolina, where the best match was at 3.0 m (+10 ft mean sea level). The 3.0-m (+10.0 ft) contour represents the seaward face of dunes near the limit of vegetation at that locality.
- 3) Compute a statistically average profile from the set of representative profiles (Fig. 3).

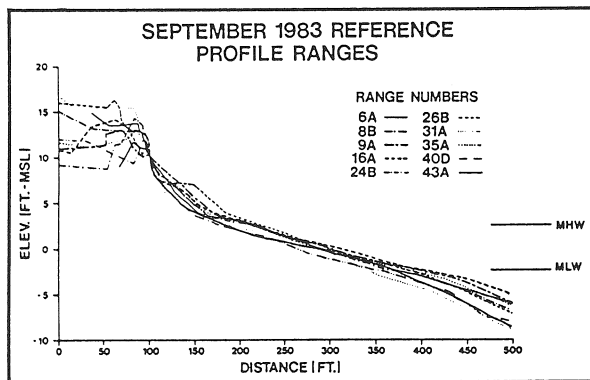


FIGURE 2.

The suite of ten representative profiles from Myrtle Beach used in computing the IPP. Profiles were aligned using the +3 m (+10 ft) NGVD contour which produced the least deviation around the mean. [Vertical exaggeration is 10:1] [From Kana et al., 1984]

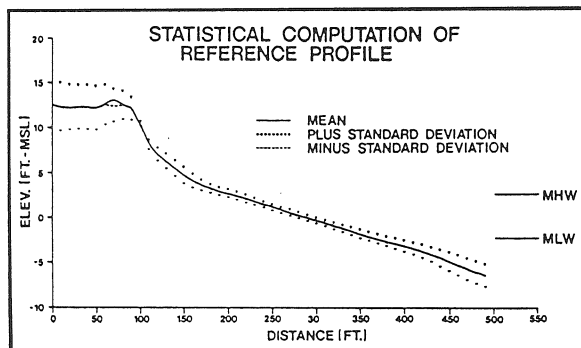


FIGURE 3.

The statistically determined IPP (10:1 vertical exaggeration) determined from the suite of profiles presented in Figure 2, showing ± 1 standard deviation around the mean (from Kana et al., 1984).

- 4) Using the match point as a starting distance, compute the unit-width volume under the profile to closure depth (where known) or an arbitrary survey limit. In the example data set, surveys extended only to low-tide wading depth [-1.5 m (-5.0 ft) MSL]. This yields an average unit-width volume typical of the area. Figure 4 illustrates the important dimensions of the *ideal* or *reference* profile for Myrtle Beach in 1984.
- 5) The *ideal* profile is then matched with all profiles in a given littoral cell by superimposing it on each survey line until the volumes equate. A practical way to do this is by means of a deficit offset curve (where the *ideal* profile volume exceeds an existing volume). This is accomplished by calculating the volume of sand in the IPP for a series of profile segments which start at the IPP +3 m (+10 ft) contour and move seaward in constant distance increments (Fig. 5). Plot this series of starting points and corresponding volumes to produce a curve (Fig. 6). This is the deficit-offset curve and indicates the offset distance associated with a given sediment deficit (Eiser and Jones, 1989).

Figure 7 contains two example plots showing the superimposition of the IPP on existing profiles. These examples represent extremes in the Myrtle Beach (Kana et al., 1984) data set; the upper example shows the *ideal* profile slightly seaward but close to an existing dune, whereas the lower example (from an armored section) shows the *ideal* profile dune crest 28 m (92 ft) landward of the seawall. In each case, the volume under existing and *ideal* profiles is equal [measured landward from -1.5 m (-5.0 ft) NGVD to the existing +3 m (+10 ft) NGVD contour]. The actual position of the dune crest was offset from the volume match line based on the statistically determined distance from the +3 m (+10 ft) contour to the dune crest of the ten profiles used in determining the ideal volume. For Myrtle Beach, the dune crest averaged 7.6 m (25 ft) landward of +3 m (+10 ft) NGVD contour (see Fig. 4).

The IPP methodology provides an objective estimate of the location of a dune line in the absence of shore-protection structures. When a number of profiles are analyzed, it is possible to draw a line from *ideal* dune crest to *ideal* dune crest that depicts an ideal planform for the particular reach in question. While this methodology will not work along tidal inlets where profiles cross swash platforms and yield highly variable unit volumes, it is adaptable to sections of beach uninterrupted by tidal inlet shoals. It can also be applied along beaches having a systematic variation in sand volume (Jones et al., 1988).

An important point of the IPP methodology is to establish a consistent, volumetrically determined starting line from which erosion rates can be applied and future shoreline positions predicted. The IPP dune line is intended to closely match the existing foredunes in the survey area (e.g., Fig. 7, upper). Sometimes, because of artificial manipulation over the years, the foredune alignment from property to property varies from the ideal.

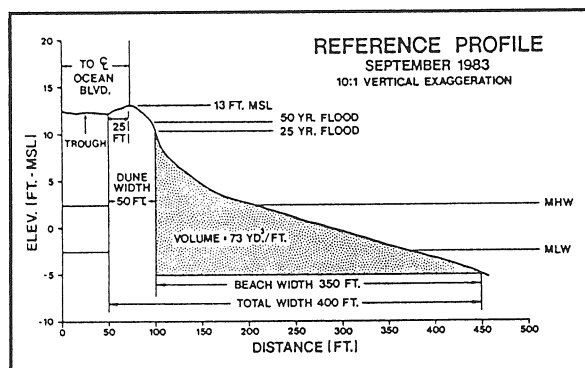


FIGURE 4.

The reference profile or IPP for Myrtle Beach showing key dimensions, based on ten representative profiles surveyed in September 1983. [From Kana et al., 1984]

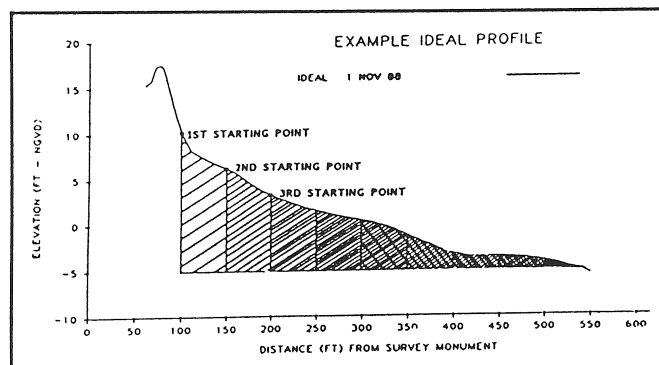


FIGURE 5.

IPP plot showing series of starting points used in volume calculations for the generation of deficit-offset curve (from Eiser and Jones, 1989).

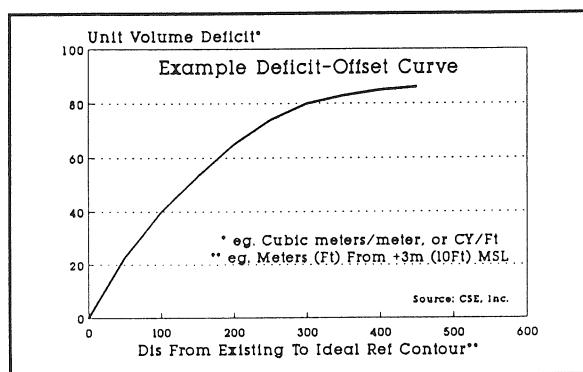


FIGURE 6. Example deficit-offset curve. [Source: CSE]

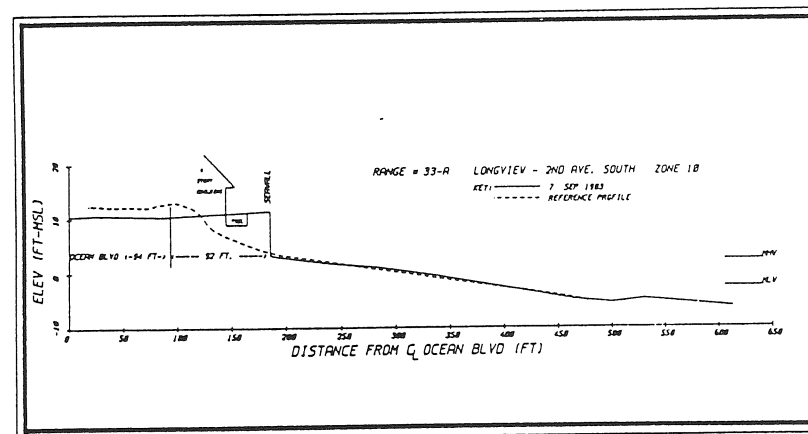
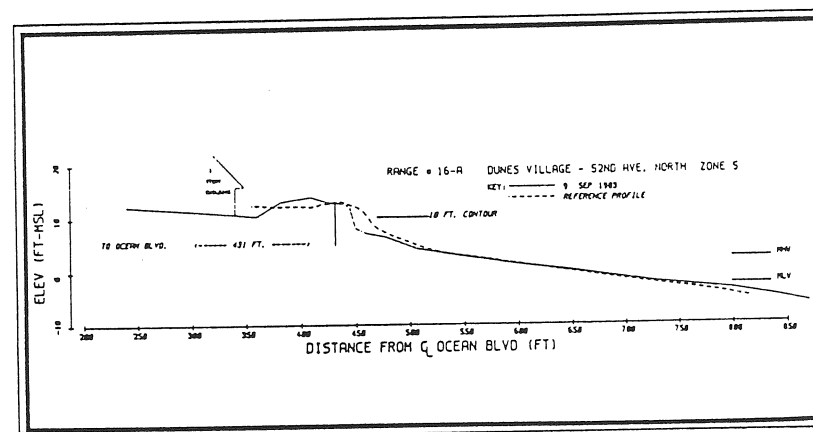


FIGURE 7. Example profile plots showing superimposition of the IPP on September 1983 profiles at Myrtle Beach, South Carolina (from Kana et al., 1984).

Figure 8 illustrates an application of the IPP methodology along Myrtle Beach. Projection of the *ideal* dune line on each profile provides a series of control points for constructing a "baseline." The baseline has become the primary line of jurisdiction in South Carolina seaward of which only rare construction activities are permitted (S.C. Beach Management Act of 1988; amended 1990). Development setback lines are constructed more or less parallel to the baseline by multiplying the local (linear) erosion rate by the number of years of interest. Where data exist, the linear erosion rate in South Carolina is developed statistically from volumetric erosion rates using results from multiple contours. Forty years is the mandated period of interest under South Carolina's Beach Management Act.

Relationship to Beach Nourishment

The IPP and setback line methodology for South Carolina provide several useful criteria for nourishment planning. First, it provides an estimate of sand deficits at a profile line by simply comparing the *ideal* volume with the existing volume seaward of shore-protection structures or scarps. With an adjustment of this volume to account for the deficit between the normal survey limit -1.5 m (-5.0 ft) NGVD and profile closure, the initial nourishment requirement for a minimal *ideal* profile can be estimated. Secondly, it provides an objective delineation of the true (existing) beach planform in the absence of structures by construction of a quantitative baseline. Third, it provides a consistent starting point for measuring erosion rates and projecting future shorelines (setback lines).

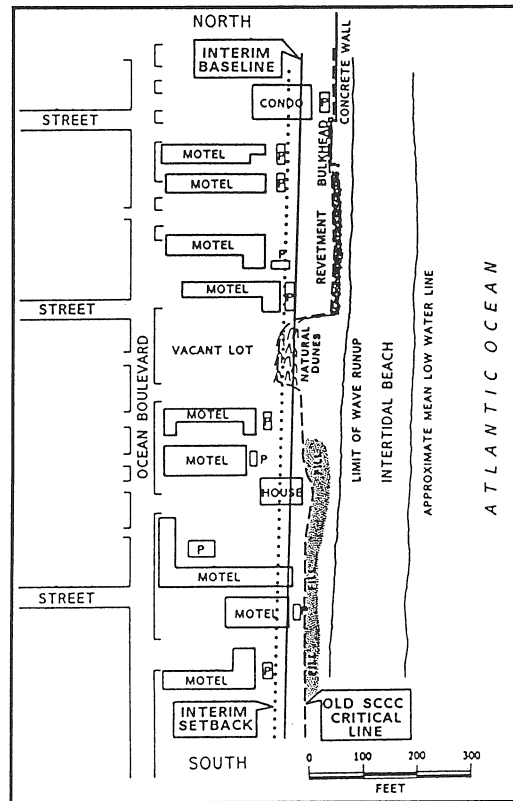


FIGURE 8. Section of Myrtle Beach shoreline in 1982 showing development, variable backshore conditions, irregular SCCC critical line (line of jurisdiction prior to 1988), and a projection of the proposed baseline and setback line using the ideal profile methodology (from Kana, 1990).

Advance nourishment requirements can be estimated by superimposing a displaced ideal profile on an existing profile, using a displacement that is related to linear erosion rates. Its primary disadvantage is its inapplicability around tidal inlets. However, the IPP provides a benchmark profile volume against which surpluses (or deficits) at inlets can be measured. Many South Carolina inlets, for example, yield profiles to the shoreline that incorporate swash platforms of the ebb-tidal delta. Profile volumes may be many times higher (or lower) than adjacent beaches, providing a measure of the relative quantities of sand trapped (or released) at an inlet. Large increases in profile volume compared to the ideal indicate the zone of influence of tidal inlets, trailing ebb shoals (at migrating inlets), or zones influenced by offshore shoals.

A range of conditions occur along South Carolina beaches as depicted in Figure 9. Armored beaches, such as portions of the Grand Strand, Folly Beach, and Hilton Head Island, have major sand deficits. At the other extreme, particularly around inlets, some profiles maintain a large surplus of sand. "Normal" beaches, containing all the features associated with a healthy beach including foredunes, dry-sand berms, and a wide intertidal profile, occur along 50 percent of South Carolina's developed coast (Kana, 1990). Unit volumes above low-tide wading depth are not constant but vary from beach to beach. There is a general trend of increasing unit volumes from north to south which correlates with a reduction in wave heights and beach grain size (Brown, 1977) and a decrease in average foreshore slope. However, numerous variations occur. Erosion rates are highly variable with only a few areas, such as the Grand Strand, considered to have a uniform rate of change over relatively long reaches.

One benefit of the IPP methodology is its applicability to areas with no comparative profile data. It provides a snapshot of existing conditions and, by comparison with similar hydrographic settings, can provide more quantitative information on the condition of a beach. If the analysis extends to the toe of the foreshore, it will incorporate the majority of variations in profile slopes and will yield similar results regardless of the season of the survey. By normalizing the analysis over unit shoreline lengths, surplus and deficit volumes are easily compared from reach to reach or between similar sites. This facilitates preparation of sediment budgets and nourishment estimates.

The final nourishment plan under the IPP methodology is related to the equilibrium shoreline planform for the area. The planform is developed by applying the IPP(s) along the project shoreline (as in Fig. 8). If some minimal beach width is desired at all sections, the reach having the greatest sand deficit will control the quantity of fill required.

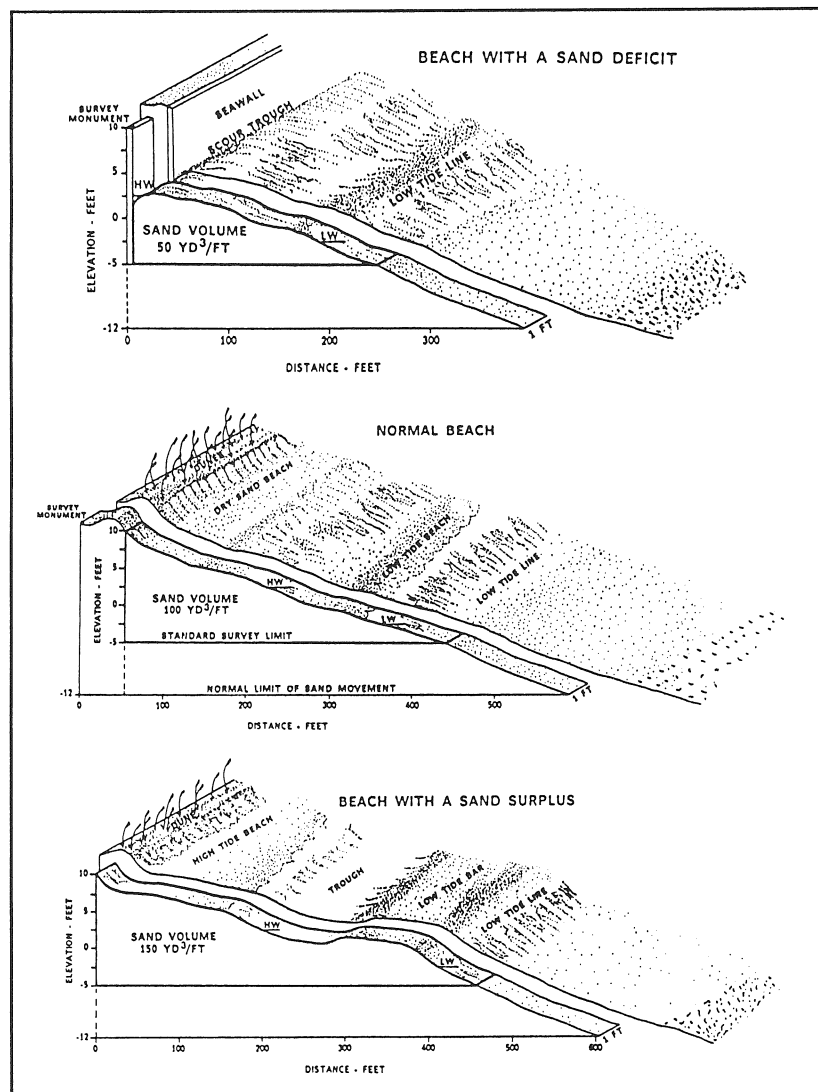


FIGURE 9. Typical range of beach conditions for South Carolina's mesotidal profiles, showing relative quantities of sand in the reference cross-section to -1.5 m (-5.0 ft) NGVD (from Kana, 1990). Closure depth is believed to range from -3 m (-10 ft) to -5 m (-16.5 ft) for most South Carolina beaches (CSE, unpublished data).

SUMMARY

The profile volume approach to nourishment places more emphasis on the quantity of sand in the profile and variations from an ideal present profile (IPP) for a given beach. From the IPP, projections can be made of equilibrium shoreline plan-forms, stable dune positions, and volumetric sand deficits or surpluses in the absence of structures. Away from inlets, the methodology detects variations in profile condition produced when structures encroach on the beach.

Definition of an ideal unit-width volume for a given beach can be arbitrary, depending on the contours selected for computation. However, by using an IPP that incorporates most of the foreshore and foredune, minor changes in beach slope can be ignored.

The profile volume approach also deals in the basic quantities used in nourishment planning--unit-width sand volumes. Once beach designers think in terms of an ideal (or desirable) unit volume and volumetric erosion rates for a given site, nourishment quantities are easier to develop. Performance of nourishment can also be related to the IPP(s) for a given beach. Consideration of beach volumes rather than single contour positions (the majority of beach analyses) is a logical improvement in nourishment design and general coastal zone management planning.

The methodology requires profile surveys which are often missing in remote areas. However, only one set of profiles is needed to define an ideal profile for a littoral cell. Successive surveys will provide an indication of whether the initial ideal profile is truly representative for the site.

REFERENCES

- Bascom, W.N. 1951. The relationship between sand size and beachface slope. *Trans. Amer. Geophys. Union*, Vol. 32, pp. 866-874.
- Brown, P.J. 1977. Variations in South Carolina morphology. *Southeastern Geology*, Vol. 18(4), pp. 249-264.
- Bruun, P. 1954. Coastal erosion and the development of beach profiles. Tech. Memo. No. 44, Beach Erosion Board, Washington, D.C.
- CERC. 1984. *Shore Protection Manual*. U.S. Army Corps of Engineers, Coastal Engineering Research Center, Ft. Belvoir, Vir.; U.S. Government Printing Office, Washington, D.C., 2 vols.
- CSE. 1990a. Seabrook Island, South Carolina, beach nourishment project. Survey Report No. 1 for Seabrook Island POA; Coastal Science & Engineering, Inc., Columbia, S.C., 41 pp. + appendices.
- CSE. 1990b. Erosion assessment and beach restoration alternatives for Hunting Island, South Carolina. Feasibility Study for South Carolina PRT; CSE, Columbia, S.C., 66 pp. + app.
- CSE. 1991. Hunting Island State Park 1991 beach nourishment. Project Plans to S.C. Department of Parks, Recreation and Tourism; CSE, Columbia, S.C., 20 plates.
- Dean, R.G. 1977. Equilibrium beach profiles: U.S. Atlantic and Gulf Coasts. Dept. Civil Engineering, Ocean Engineering Rept. No. 12, University of Delaware, Newark.

- Dean, R.G. 1991. Equilibrium beach profiles: characteristics and applications. *Jour. Coastal Research*, Vol. 7(1), pp. 53-83.
- Eiser, W.C., and C.P. Jones. 1989. Analysis of beach survey data along the South Carolina coast — fall 1988. Final Report to South Carolina Coastal Council; CSE, Columbia, S.C., 63 pp. + appendices.
- Gundlach, E.R., B.J. Baca, A. Frankenburg, M.L. Williams, and T.W. Kana. 1985. Myrtle Beach nourishment project. Geotechnical, Survey, and Ecological Data Report for City of Myrtle Beach; RPI Coastal Science, Inc. (Columbia, S.C.), and Olsen Associates, Inc. (Jacksonville, Fla.), 43 pp. + 4 data appendices.
- Hayes, M.O. 1979. Barrier island morphology as a function of tidal and wave regime. In S. Leatherman (ed.), *Barrier Islands*, Academic Press, New York, N.Y., pp. 1-27.
- Hayes, M.O. 1980. General morphology and sediment patterns in tidal inlets. *Sedimentary Geology*, Vol. 26, pp. 139-156.
- Inman, D.L., and C.F. Nordstrom. 1971. On the tectonic and morphologic classification of coasts. *Jour. Geol.*, Vol. 79, pp. 1-21.
- Jones, C.P., D.M. Scaturro, T.W. Kana, and W.C. Eiser. 1988. Calculation of interim baselines and 40-year setback lines. Final Report to South Carolina Coastal Council (Charleston); CSE, Columbia, S.C., 60 pp. + appendices.
- Kana, T.W. 1990. Conserving South Carolina beaches through the 1990's: a case for beach nourishment. Booklet: South Carolina Coastal Council, Charleston, S.C., 30 pp.
- Kana, T.W., and F.D. Stevens. 1992. Coastal geomorphology and sand budgets applied to beach nourishment. In *Coastal Engineering Practice '92, Proceedings of a Specialty Conference on the Planning, Design, Construction, and Performance of Coastal Engineering Projects*; ASCE, New York, N.Y., pp. 29-44.
- Kana, T.W., S.J. Siah, and M.L. Williams. 1984. Analysis of historical erosion rates and prediction of future shoreline positions, Myrtle Beach, South Carolina. Project Report for City of Myrtle Beach; RPI Coastal Science, Inc., Columbia, S.C., 130 pp.
- Kana, T.W., M.L. Williams, and F.D. Stevens. 1985. Managing shoreline changes in the presence of nearshore shoal migration and attachment. In *Proc. Coastal Zone '85*, ASCE, New York, N.Y., pp. 1277-1294.
- Komar, P.D. 1976. *Beach Processes and Sedimentation*. Prentice Hall, Englewood Cliffs, N.J., 429 pp.
- Nummedal, D., and I.A. Fischer. 1979. Process-response models for depositional shorelines: the German and the Georgia Bights. In *Proc. 16th Coastal Engineering Conf.*, ASCE, New York, N.Y., pp. 1215-1231.
- Olsen Associates. 1989. Hilton Head Island beach nourishment. Project Plans to Town of Hilton Head Island, South Carolina, 15 plates.
- Sexton, W.J., and M.O. Hayes. 1983. Natural bar bypassing of sand at a tidal inlet. In *Proc. Coastal Engineering '82*, ASCE, New York, N.Y., pp. 1479-1495.
- Shepard, F.P. 1963. *Submarine Geology*. Harper & Row, New York, N.Y., 557 pp.
- Siah, S.J., E.J. Olsen, and T.W. Kana. 1985. Myrtle Beach nourishment project. Engineering Report for City of Myrtle Beach. RPI Coastal Science, Inc. (Columbia, S.C.), and Olsen Associates, Inc. (Jacksonville, Fla.), 160 pp. + appendices.
- USACE. 1992. Folly Beach, South Carolina, beach nourishment project plans. U.S. Army Engineer District, Charleston, S.C., 10 plates.
- Wiegel, R.L. 1964. *Oceanographical Engineering*. Prentice Hall, Englewood Cliffs, N.Y., 532 pp.
- Work, P.A., and R.G. Dean. 1991. Effect of varying sediment size on equilibrium beach profiles. In *Proc. Coastal Sediments '91*, ASCE, New York, N.Y., pp. 890-904.